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(54) Abstract Title

**A method for lowering nitrogen oxide content in vehicle engine exhaust gas**

(57) A method for lowering the nitrogen oxide content in the exhaust gas from an internal-combustion engine 1 which can be operated alternately under lean and rich conditions, has a control unit 11 and has an exhaust pipe 2, in which a starting catalytic converter 3, a nitrogen oxide storage catalytic converter 4 and an SCR catalytic converter 5 are arranged one behind the other as seen in the direction of flow, and with recurring nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter 4. The NH<sub>3</sub> loading of the SCR catalytic converter is determined by the control unit 11, and the formation of nitrogen oxides by the internal-combustion engine 1 is increased at least within the nitrate regeneration phases, the SCR catalytic converter 5 in the exhaust pipe 2 being arranged at least sufficiently far downstream of the nitrogen oxide storage catalytic converter 4 for a temperature which is approximately 50°C to approximately 150°C lower than at the entry to the nitrogen oxide storage catalytic converter 4 to be established at the entry to the SCR catalytic converter 5 in most of the intended operating range of the internal-combustion engine 1.

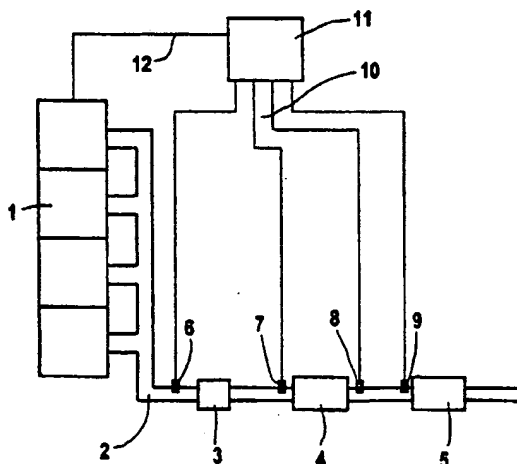


FIG. 1

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1/2

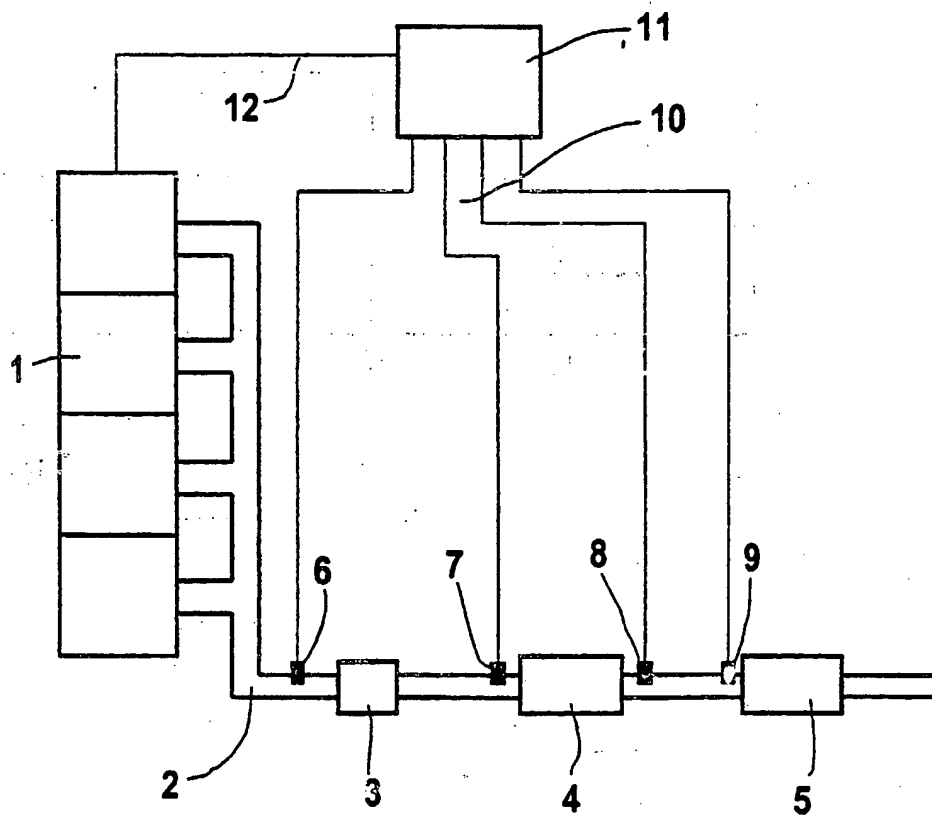


FIG. 1

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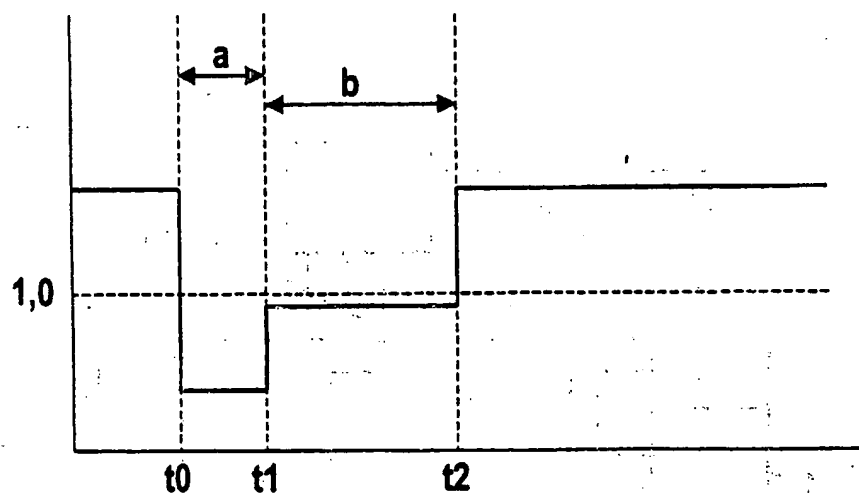


FIG. 2

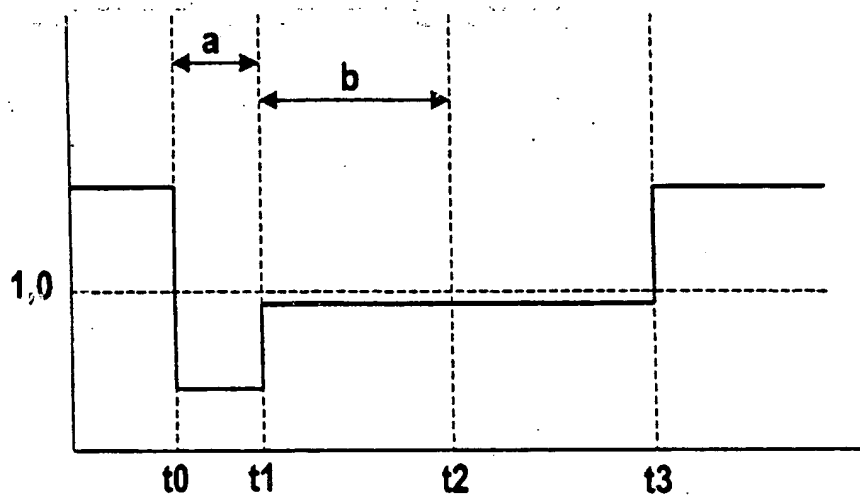


FIG. 3

A method for lowering the nitrogen oxide content in the exhaust gas  
from an internal-combustion engine

The present invention relates to a method for lowering the nitrogen oxide content in the exhaust gas from an internal-combustion engine operable selectively under lean and rich conditions.

Known exhaust-gas cleaning installations with catalytic converters have, one behind the other as seen in the direction of flow, a starting catalytic converter, a nitrogen oxide storage catalytic converter and an SCR catalytic converter, are used in particular in motor vehicles which have an internal-combustion engine which can be operated under lean-burn and fuel-rich-burn conditions, in the form of a direct-injection spark-ignition engine. For removal of nitrogen oxides, when the internal-combustion engine is operating under lean-burn conditions, barium carbonate which is present, for example, in the catalyst material of the nitrogen oxide storage catalytic converter removes nitrogen oxides (NO<sub>x</sub>) from the exhaust gas, which is at that time oxidizing, to form solid barium nitrate. On account of the associated load imposed on the material, from time to time it is necessary to regenerate the NO<sub>x</sub> storage catalytic converter. This process, which is known as nitrate regeneration, is effected by operating the internal-combustion engine under rich-burn conditions for a certain time. The barium nitrate, which is unstable in the resulting exhaust gas containing reducing agent, in the process decomposes again to form barium carbonate and to release NO<sub>x</sub>. The latter are then reduced by the reducing agents (H<sub>2</sub>, CO and HC) present in the exhaust gas, at the precious metal component which is applied to the NO<sub>x</sub> storage catalytic converter, predominantly to form harmless nitrogen (N<sub>2</sub>). Accordingly, lowering the levels of NO<sub>x</sub> over a prolonged period using the process described requires recurring alternation of the internal-combustion engine between lean and rich conditions, but it should be noted that the rich-burn operation which is required for the nitrate regeneration operations diminishes the benefit in terms of fuel consumption by the internal-combustion engine which is achieved in lean-burn operation. Therefore, with a view to minimising fuel consumption, it is desirable for the proportion of time taken up by lean-burn operation to be as high as possible. Particularly in the case of a direct-injection spark-ignition engine as the internal-combustion engine for a motor

vehicle, however, lean-burn operation, for combustion reasons, is only possible under a low load or a part load, and consequently, at higher loads, internal-combustion engines of this type are operated with an approximately stoichiometric or even a rich (substoichiometric) air/fuel ratio.

Under the reducing exhaust-gas conditions which are present in rich-burn operation, NOx is partly reduced, at a conventional NOx storage catalytic converter, by H<sub>2</sub> contained in the exhaust gas, to form highly odorous and harmful ammonia (NH<sub>3</sub>). Primarily, however, the formation of NH<sub>3</sub> takes place at a starting catalytic converter connected upstream of the NOx storage catalytic converter. If a suitable SCR (Selective Catalytic Reduction) catalytic converter is connected downstream of the NOx storage catalytic converter, this SCR catalytic converter having the ability to store NH<sub>3</sub> under reducing (rich) conditions and to catalyze the reaction of the stored NH<sub>3</sub> with NOx to form harmless N<sub>2</sub> under oxidizing (lean) conditions, the NOx emissions are advantageously lowered further in alternating rich and lean operation. Therefore, the combination of NOx storage catalytic converter and SCR catalytic converter makes it possible to considerably extend the lean-burn operating phases of the internal-combustion engine without any adverse effect on the lowering of the levels of Nox. If appropriate, it may be advantageous to increase the provision of NH<sub>3</sub> by increasing the levels of NOx formed by the internal-combustion engine.

An internal-combustion engine of the known type with appropriate exhaust-gas after treatment device is known from the laid-open specification EP 0 802 315 A2.

For example, an embodiment shown in Fig. 13 of EP 0 802 315 A2 shows a catalytic converter arrangement having a starting catalytic converter, which is designed as a three-way catalytic converter with an increased ability to form NH<sub>3</sub>, upstream of a NOx storage catalytic converter and following SCR catalytic converter. A first drawback is that the efficiency of the known NOx storage catalytic converters drops considerably below approx. 250°C and above approx. 450°C. Secondly, it should be noted that typical SCR catalytic converters can only be used to good effect in a temperature range between approx. 200°C and approx. 450°C. The ability to store NH<sub>3</sub> is highest at low temperatures and decreases to a greater or lesser extent as the temperature rises.

The result is that the time and duration of rich-burn operation for generating  $\text{NH}_3$  as a function of the temperature of the  $\text{NO}_x$  storage catalytic converter and of the SCR catalytic converter have a decisive influence on the consumption and the emissions of  $\text{NO}_x$  from the internal-combustion engine which is alternately operated under lean and rich conditions.

Therefore, the present invention seeks to provide a method for operating an installation of the type described in the introduction in which the provision of  $\text{NH}_3$ , the amount of  $\text{NH}_3$  stored in the SCR catalytic converter, the  $\text{NO}_x$  storage mode and the nitrate regeneration mode of the  $\text{NO}_x$  storage catalytic converter are adapted to one another, taking account of the particular state of the catalytic converter, in such a way that the  $\text{NO}_x$  level in the exhaust gas can be lowered as efficiently as possible within the widest possible operating range of the internal-combustion engine.

According to the present invention there is provided a method for lowering the nitrogen oxide content in the exhaust gas from an internal-combustion engine operable selectively under lean and rich conditions, has a control unit and has an exhaust pipe, in which a starting catalytic converter, a nitrogen oxide storage catalytic converter and an SCR catalytic converter are arranged one behind the other in the direction of flow, recurring nitrate regeneration phases being carried out in order to regenerate the nitrogen oxide storage catalytic converter, wherein the  $\text{NH}_3$  loading of the SCR catalytic converter is determined by the control unit, and the formation of nitrogen oxides by the internal-combustion engine is increased at least within the nitrate regeneration phases, the SCR catalytic converter in the exhaust pipe being arranged at least sufficiently far downstream of the nitrogen oxide storage catalytic converter for a temperature which is approximately  $50^\circ\text{C}$  to approximately  $150^\circ\text{C}$  lower than at the entry to the nitrogen oxide storage catalytic converter to be established at the entry to the SCR catalytic converter in most of the intended operating range of the internal-combustion engine.

The method according to the invention is based on the control unit determining the  $\text{NH}_3$  loading of the SCR catalytic converter, with the result that the amount of  $\text{NH}_3$  which is available for reducing the levels of  $\text{NO}_x$  in the SCR catalytic converter during

lean-burn operation can be evaluated. If the control unit determines that the  $\text{NH}_3$  loading of the SCR catalytic converter has been lowered excessively, the rich-burn operation of the internal-combustion engine which is required for nitrate regeneration of the  $\text{NO}_x$  storage catalytic converter is utilized, at least during the nitrate regeneration phases of the  $\text{NO}_x$  storage catalytic converter, to form  $\text{NH}_3$  by the reduction of  $\text{NO}_x$  to  $\text{NH}_3$  which takes place, for example, at the starting catalytic converter. The formation of  $\text{NO}_x$ , which is usually relatively low in rich-burn operation, is increased, so that it becomes possible, within the short time required for nitrate regeneration, to achieve a correspondingly great increase in the  $\text{NH}_3$  loading of the SCR catalytic converter. The nitrate regeneration process is not impaired by the increase in the formation of nitrogen oxides. In this way, the SCR and  $\text{NO}_x$  storage catalytic converters are restored to an active state with regard to lowering the levels of  $\text{NO}_x$  and can then be used again for a correspondingly long period to lower the levels of  $\text{NO}_x$  in lean-burn operation, which is advantageous in terms of fuel consumption. The process according to the invention has the advantageous result that considerably fewer additional  $\text{NH}_3$  generation phases with the associated drawbacks in terms of fuel consumption are required. Expanding lean-burn operation, in terms of the operating range of the internal-combustion engine, to higher loads and therefore to higher exhaust-gas temperatures can be achieved as a result of the SCR catalytic converter being arranged at least sufficiently far downstream of the  $\text{NO}_x$  storage catalytic converter for a temperature which is approximately  $50^\circ\text{C}$  to approximately  $150^\circ\text{C}$  lower than at the entry to the  $\text{NO}_x$  storage catalytic converter to be established at the entry to the SCR catalytic converter in most of the intended operating range of the internal-combustion engine. As a result, the SCR catalytic converter can continue to be used to lower the levels of  $\text{NO}_x$  even if, with the  $\text{NO}_x$  storage catalytic converter arranged upstream, the upper temperature limit of the range of action is exceeded, and therefore it can make little or no contribution to lowering the levels of  $\text{NO}_x$ . In this context, the term most of the intended operating range of the internal-combustion engine is to be understood as meaning the operating range during standard driving after warming-up has been completed.

The measures listed in the subclaims allow advantageous refinements and improvements to the method described in Claim 1.

Preferably, an upper threshold S1 is preset for the NH<sub>3</sub> loading of the SCR catalytic converter, and at least within the nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter the formation of nitrogen oxides by the internal-combustion engine is increased if the NH<sub>3</sub> loading of the SCR catalytic converter has fallen below the threshold S1.

In this way, the decision as to whether it is necessary to increase the NH<sub>3</sub> loading of the SCR catalytic converter is linked to the formation of an upper threshold S1 for the NH<sub>3</sub> loading of the SCR catalytic converter. If the level falls below the threshold S1 formed by the control unit, the NH<sub>3</sub> loading is increased by increasing the formation of NO<sub>x</sub> by the internal-combustion engine at least within the nitrate regeneration phases of the NO<sub>x</sub> storage catalytic converter. The reduction of NO<sub>x</sub> to NH<sub>3</sub> which takes place, for example, at the starting catalytic converter makes use of the increased emissions of NO<sub>x</sub> to form NH<sub>3</sub>.

In a further refinement, a lower threshold S2 is preset for the NH<sub>3</sub> loading of the SCR catalytic converter, and the formation of nitrogen oxides by the internal-combustion engine is only increased within the nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter if the NH<sub>3</sub> loading of the SCR catalytic converter has fallen below the threshold S1 but not below the threshold S2. Thus, the evaluation of the current NH<sub>3</sub> loading of the SCR catalytic converter is even more finely tuned as a result of the control unit forming, in addition to the upper threshold S1, a lower threshold S2 for the NH<sub>3</sub> loading of the SCR catalytic converter. If the NH<sub>3</sub> loading lies in the range between S1 and S2, it is indicated to the control unit that, apart from the increase in the NO<sub>x</sub> formation which is performed during the nitrate regeneration phases and the subsequent reduction of NO<sub>x</sub> to form NH<sub>3</sub>, no further measures are required to increase the NH<sub>3</sub> loading of the SCR catalytic converter. Combining nitrate regeneration and NH<sub>3</sub> formation advantageously leads to optimum use being made of the rich-burn operation which is required as a result, so that the associated fuel consumption is minimized.

Preferably, the thresholds S1 and S2 for the NH<sub>3</sub> loading of the SCR catalytic converter are advantageously predetermined as a function of the temperature of the SCR



catalytic converter and of the load demand on the internal-combustion engine. The temperature dependency of the thresholds S1 and S2 may, for example, be based on the maximum quantity of  $\text{NH}_3$  which can be taken up by the SCR catalytic converter, which in turn is very considerably dependent on the temperature of the SCR catalytic converter. In this way, the thresholds can be adapted to the instantaneous capacity of the SCR catalytic converter to take up  $\text{NH}_3$ . The temperature dependency of the maximum  $\text{NH}_3$  loading of the SCR catalytic converter, which is present through allocation of values or in some other way, is expediently stored in a memory of the control unit which, as is customary, additionally has functions for inputting and outputting data and data-processing functions.

Furthermore, in an advantageous embodiment, it has proven expedient, after a cold start has taken place, for the formation of  $\text{NO}_x$  by the internal-combustion engine to be additionally increased at least from time to time during the warming-up phase of the internal-combustion engine which is in any case carried out with a rich air/fuel ratio. This procedure leads to  $\text{NH}_3$  being formed, for example, at the starting catalytic converter even while the internal-combustion engine is warming up and to this  $\text{NH}_3$  being deposited in the SCR catalytic converter. At the time of warming-up, this catalytic converter is still at a relatively low temperature and is therefore able to take up relatively large amounts of  $\text{NH}_3$ . Therefore, when the engine is warming up, as soon as the lower temperature limit for its range of action is reached, the SCR catalytic converter has stored  $\text{NH}_3$  for lowering the levels of  $\text{NO}_x$ .

A preferred embodiment of the invention is illustrated in simplified form in the drawing and is explained in more detail in the following description, in which:

Fig. 1 shows a diagrammatic block diagram of an internal-combustion engine with associated exhaust-gas cleaning installation,

Fig. 2 shows a diagram illustrating the time profile of the air/fuel ratio of the internal-combustion engine shortly before, during and shortly after the nitrate regeneration of the  $\text{NO}_x$  storage catalytic converter, and

Fig. 3 shows a further diagram illustrating the time profile of the air/fuel ratio of the internal-combustion engine shortly before, during and shortly after the nitrate regeneration of the NOx storage catalytic converter.

The installation which is diagrammatically depicted in Fig. 1 is used to clean the exhaust gas from an internal-combustion engine, as is used, for example, in a motor vehicle and is designed, for example, in the form of a direct-injection spark-ignition engine. The installation has a starting catalytic converter 3, which is arranged close to the engine in an exhaust pipe 2 and, downstream of the starting catalytic converter, an NOx storage catalytic converter 4 and an SCR catalytic converter 5; the latter catalytic converters 4, 5 may be installed underneath the floor of the motor vehicle. Furthermore, an oxygen sensor 6, which is used as a signal transmitter for controlling the air/fuel ratio of the internal-combustion engine 1 during operation which alternates between lean and rich conditions, is incorporated in the exhaust pipe 2 upstream of the starting catalytic converter 3. On the outlet side of the NOx storage catalytic converter 4, a sensor 8 which is sensitive to NOx and NH<sub>3</sub> is accommodated in the exhaust pipe 2. In the sketched installation, it is possible to measure the temperature by suitably positioned temperature sensors 7 and 9 on the entry side of NOx storage catalytic converter 4 and SCR catalytic converter 5. The signals of the sensors 6, 7, 8, 9 are fed to the control unit 11 as input variables via measurement lines 10. The functionality implemented in the control unit 11 results in the internal-combustion engine 1 being controlled by means of a control line 12 between internal-combustion engine 1 and control unit 11.

On account of its catalytic coating, the starting catalytic converter 3 which is illustrated in Fig. 1 acts both as an oxidation catalytic converter and also has the property, under the reducing conditions of rich-burn operation of the internal-combustion engine, of chemically reducing the NOx which is present in the exhaust gas to form NH<sub>3</sub>. By contrast, the NOx storage catalytic converter 4 has the ability, under the oxidizing conditions of lean-burn operation of the internal-combustion engine 1, to take up the NOx which is present in the exhaust gas, primarily through chemical bonding to the coating material to form nitrates, and of releasing the NOx again under reducing conditions and converting the vast majority of the NOx into harmless nitrogen. The SCR catalytic converter 5 arranged downstream of the NOx storage catalytic converter 4 has

the property, which is also known, for example, from the power plant sector, of being able to store  $\text{NH}_3$  under reducing conditions and being able to use this stored  $\text{NH}_3$  as a reaction partner in a selective catalytic reduction reaction, to form nitrogen, in order to chemically reduce  $\text{NO}_x$ , under oxidizing conditions.

The latter property is utilized in particular to make  $\text{NO}_x$  harmless by means of the abovementioned selective reduction reaction. The  $\text{NO}_x$  results from the  $\text{NO}_x$  storage material becoming increasingly exhausted during the  $\text{NO}_x$  storage under lean-burn operation of the internal-combustion engine (increasing  $\text{NO}_x$  slippage). However, a condition for this behaviour of the SCR catalytic converter 5 is that it be provided beforehand with suitable quantities of  $\text{NH}_3$  for storage. This is achieved by setting reducing conditions, i.e. by setting rich-burn operation of the internal-combustion engine 1 and establishing the abovementioned  $\text{NH}_3$  formation at the starting catalytic converter 3. Depending on the demand for  $\text{NH}_3$ , it may be necessary for the  $\text{NH}_3$  formation to be increased by increasing to a greater or lesser extent the  $\text{NO}_x$  formation, which is usually relatively low during rich-burn operation of the internal-combustion engine 1. This is achieved by increasing the combustion temperatures in the combustion chamber, which in turn is achieved by shifting the ignition angle to an earlier position in the case of a spark-ignition internal-combustion engine or by making the fuel injection take place earlier.

If the amount of  $\text{NO}_x$  slippage in lean-burn operation of the internal-combustion engine 1 has risen to an unacceptable level, the  $\text{NO}_x$  storage catalytic converter 4 has to be subjected to nitrate regeneration by providing reducing agent, a step which can likewise be effected by switching the internal-combustion engine from lean-burn operation to rich-burn operation. Overall, the recurring alternation between lean-burn operation and rich-burn operation which has been described results in effective removal of  $\text{NO}_x$  from the exhaust gas from the internal-combustion engine 1. Compared to an exhaust-gas installation which is equipped only with an  $\text{NO}_x$  storage catalytic converter, the length of the lean-burn operating phases can be considerably extended through the interaction of  $\text{NO}_x$  storage catalytic converter 4 and SCR catalytic converter 5, and in this way a correspondingly greater saving on fuel consumption can also be achieved.

The NOx storage catalytic converter 4 is typically highly effective within a temperature range from approximately 250°C to 450°C, and the SCR catalytic converter 5 is typically highly effective in a temperature range (temperature window) from 200°C to 450°C. In view of the range of the temperature window, the distance of the SCR catalytic converter 5 from the NOx storage catalytic converter 4 is selected in such a way that, after warming up has taken place, the SCR catalytic converter 5, in true driving mode, is at a temperature which is approximately 50°C to 150°C lower than that of the upstream NOx storage catalytic converter 4. The result is that the SCR catalytic converter 5 remains active even when, for example, as a result of an increased engine load, the temperature of the NOx storage catalytic converter 4 has risen to up to 600°C, so that it has become inactive. The SCR catalytic converter remains active since it is at a lower temperature. Consequently, this combined catalytic converter system results in a widened operating temperature window of approximately 250°C to 600°C, based on the exhaust-gas temperature on entry into the NOx storage catalytic converter 4, and it is therefore also possible for the internal-combustion engine 1 to be operated under lean conditions within a widened load range. Special design measures, such as for example a specially designed exhaust pipe 2 or the use of special measures for cooling the exhaust gas, allow the temperature difference of approximately 50°C to 150°C which is usually present between NOx catalytic converter 4 and SCR catalytic converter 5 to be increased still further should this prove necessary on account of the engine characteristics or the nature of the catalytic converters used.

Depending on the temperature of the respective catalytic converters 4, 5 which is determined by the temperature sensors 7 and 9, either the internal-combustion engine 1 is operated so as to purely alternate between lean and rich conditions, without additional NH<sub>3</sub> generation, so that it is primarily the NOx catalytic converter 4 which is responsible for reducing the levels of NOx, or the levels of NOx are lowered completely or partially at the SCR catalytic converter 5, which, however, requires the latter to have a sufficient quantity of stored NH<sub>3</sub>. The NH<sub>3</sub> loading which is present in the SCR catalytic converter 5 is determined by a sensor measurement, on the outlet side of the NOx storage catalytic converter 4, of the concentration of NOx and NH<sub>3</sub>. In the present case, this is achieved with the aid of the NOx/NH<sub>3</sub> sensor 8, which is sensitive to NOx and NH<sub>3</sub>, taking account of the exhaust-gas flow which is determined by the engine load, in the control

unit 11 by ongoing addition of the NO<sub>x</sub> and NH<sub>3</sub> mass flowrates calculated in the control unit. In the process, the fact that NO<sub>x</sub> which is introduced into the SCR catalytic converter 5, through reaction with stored NH<sub>3</sub>, correspondingly reduces the NH<sub>3</sub> loading is also taken into account. However, the determination of the NH<sub>3</sub> loading of the SCR catalytic converter 5 can also be carried out using separate sensors for the NO<sub>x</sub> and NH<sub>3</sub> concentration or in model-based form, in which case use is made, for example, of corresponding characteristic diagrams, which are stored in the control unit 11, for the temperature of the catalytic converters 3, 4, 5, the NO<sub>x</sub> emission from the internal-combustion engine 1 or further important variables.

If the control unit 11 detects a fall in the NH<sub>3</sub> loading, the NO<sub>x</sub> formation by the internal-combustion engine 1 is increased for at least part of the nitrate regeneration of the NO<sub>x</sub> storage catalytic converter 4, and, under the reducing conditions of the rich air/fuel ratio which are simultaneously present, the increased emission of NO<sub>x</sub> is to a very large extent reduced to NH<sub>3</sub> at the starting catalytic converter 3. A suitable upper threshold S1 and a suitable lower threshold S2 are expediently set for the NH<sub>3</sub> loading of the SCR catalytic converter 5. These thresholds S1, S2 are, for example, placed into a defined relationship with the known temperature-dependent maximum NH<sub>3</sub> loading of the SCR catalytic converter 5. In this way, the NH<sub>3</sub> loading of the SCR catalytic converter 5 can be evaluated, and it is possible to react appropriately to different degrees of lowering of the NH<sub>3</sub> loading.

A dependent relationship of the thresholds S1, S2 and S3 on the load demand imposed on the internal-combustion engine 1, which relationship is likewise stored in the control unit 11 and, for example, rises continuously, is used to take into account the fact that, given a high NH<sub>3</sub> loading of the SCR catalytic converter 5, the formation of NO<sub>x</sub> is only increased or the formation of NH<sub>3</sub> is only triggered at a relatively high load demand, and conversely, given a low NH<sub>3</sub> loading of the SCR catalytic converter 5, the formation of NO<sub>x</sub> is increased or the formation of NH<sub>3</sub> triggered even at a relatively low load demand, so that a certain NH<sub>3</sub> loading of the SCR catalytic converter 5 is constantly maintained.

The procedure when the  $\text{NH}_3$  loading of the SCR catalytic converter 5 has fallen below the threshold S1 but has not fallen below the threshold S2 is explained below with reference to the time profile, shown in Fig. 2, of the air/fuel ratio shortly before, during and shortly after the nitrate regeneration of the  $\text{NO}_x$  storage catalytic converter 4.

The range from S1 to S2 for the  $\text{NH}_3$  loading of the SCR catalytic converter 5 is selected in such a way that  $\text{NH}_3$  formation at the upstream catalytic converters 3 and 4 within the nitrate regeneration phases of the  $\text{NO}_x$  storage catalytic converter 4 which are in any case required from time to time can be regarded as a suitable way of sufficiently increasing again the  $\text{NH}_3$  loading of the SCR catalytic converter 5. If the  $\text{NO}_x/\text{NH}_3$  sensor 8 measures a correspondingly high  $\text{NO}_x$  slippage from the  $\text{NO}_x$  storage catalytic converter 4, the nitrate regeneration of this catalytic converter 4 is initiated at time  $t_0$ . For this purpose, starting from the lean air/fuel ratio of well above 1.0, first of all, in a first phase a, the operation of the internal-combustion engine is briefly switched to a very rich air/fuel ratio of less than 0.8. The reason for this is that in this way the oxygen which is stored during lean-burn operation can be removed from the storage material of the  $\text{NO}_x$  storage catalytic converter 4 within a very short time. Then, at time  $t_1$ , the engine is switched to a slightly rich air/fuel ratio, preferably of between 0.90 and 0.995, and the nitrate regeneration is continued. The transition from very rich conditions to a slightly rich air/fuel ratio may also be gradual instead of the sudden change illustrated in Fig. 2. At the same time, the low level of  $\text{NO}_x$  formed by the internal-combustion engine 1 which is customary under these conditions is increased by shifting to an earlier ignition angle and/or an earlier time of fuel injection. The  $\text{NO}_x$  which is generated by the engine in this way, under the slightly rich conditions which then prevail, is almost completely converted into  $\text{NH}_3$ , primarily at the starting catalytic converter 3 arranged close to the engine, but also at the following  $\text{NO}_x$  storage catalytic converter 4, and is then stored in the SCR catalytic converter 5, with the result that the  $\text{NH}_3$  loading of the latter is increased. After this second phase b of the nitrate regeneration has ended at time  $t_2$ , the engine reverts to a high air/fuel ratio used in lean-burn operation, and the ignition angle and start of fuel injection are restored to the intended levels. Shortly before the next nitrate regeneration commences, a decision is reached, on the basis of the  $\text{NH}_3$  loading of the SCR catalytic converter 5 which is then present, as to whether it is possible to

dispense with additional measures for generating NO<sub>x</sub> (NH<sub>3</sub> loading > S1) or whether such measures are required (NH<sub>3</sub> loading < S1).

If the NH<sub>3</sub> loading of the SCR catalytic converter 5 has fallen below the threshold S2, further additional measures are required in order to increase the formation of NO<sub>x</sub> and of NH<sub>3</sub>. The corresponding procedure for controlling the internal-combustion engine is shown by way of example with reference to the time profile, shown in Fig. 3, of the air/fuel ratio shortly before, during and shortly after the nitrate regeneration of the NO<sub>x</sub> storage catalytic converter 4.

Also, if the NH<sub>3</sub> loading has fallen below the threshold S2, the lean-burn operation of the internal-combustion engine 1 is initially retained until there is a need for nitrate regeneration of the NO<sub>x</sub> storage catalytic converter 4. Then, the nitrate regeneration is carried out with a brief highly enriched air/fuel ratio of less than 0.8 in part a and with increased formation of NO<sub>x</sub> in the second part b. However, in this case the greater fall in the NH<sub>3</sub> loading of the SCR catalytic converter 5 is reacted to by continuing to maintain the conditions of the second part b of the nitrate regeneration. Specifically, the increased formation of NO<sub>x</sub> as a result of the ignition angle being shifted to an earlier position and/or an earlier start of injection, at the slightly rich air/fuel ratio between preferably 0.9 and 0.995, is maintained even after the nitrate regeneration of the NO<sub>x</sub> storage catalytic converter 4 has concluded at time t<sub>2</sub>, until time t<sub>3</sub> in order for further NH<sub>3</sub> to be formed. Since, after the nitrate regeneration has ended at time t<sub>2</sub>, the NO<sub>x</sub> storage catalytic converter 4 has been freed of stored oxygen or nitrate which has an oxidizing action, effective formation of NH<sub>3</sub> takes place even at this catalytic converter 4 under the ongoing slightly rich conditions. Consequently, the set conditions, which are unfavourable in terms of fuel consumption, therefore generally only have to be retained for a short time beyond t<sub>2</sub>, since the NH<sub>3</sub> loading of the SCR catalytic converter 5 can be increased again correspondingly quickly.

If the NH<sub>3</sub> loading of the SCR catalytic converter 5 has fallen below the threshold S2 and at the same time, for example, as a result of particular operating conditions, increased performance is demanded of the SCR catalytic converter, an air/fuel ratio of preferably between 0.9 and 0.995 is preferably established immediately,

without taking account of whether this would be necessary and expedient with a view to nitrate regeneration of the NO<sub>x</sub> storage catalytic converter. At the same time, the formation of NH<sub>3</sub> is increased by additionally increasing the formation of NO<sub>x</sub> by shifting the ignition angle to an earlier position and/or setting an earlier start of injection. This allows a rapid rise in the NH<sub>3</sub> loading of the SCR catalytic converter 5 to be achieved, so that it is possible to switch back to the desired lean-burn operation of the internal-combustion engine 1 correspondingly quickly.

The high ability of the SCR catalytic converter 5 to store NH<sub>3</sub> at low temperature, and the rich air/fuel ratio which is generally already present during a cold start or warming-up of the internal-combustion engine 1 are advantageously utilized by carrying out even the cold start or warming-up of the internal-combustion engine 1 in such a way that there is an increased formation of NO<sub>x</sub>. As a result of shifting the ignition angle to an earlier position and/or setting an earlier start of injection, this formation of NO<sub>x</sub> is only started when the starting catalytic converter 3 has reached the minimum temperature required to convert NO<sub>x</sub> into NH<sub>3</sub>. This ensures that NH<sub>3</sub> is stored in the SCR catalytic converter 5 at the earliest possible time during operation of the internal-combustion engine, and therefore the SCR catalytic converter 5, as soon as it reaches its operating temperature, is available for reducing the levels of NO<sub>x</sub> in lean-burn operation.



### Claims

1. A method for lowering the nitrogen oxide content in the exhaust gas from an internal-combustion engine operable selectively under lean and rich conditions, has a control unit and has an exhaust pipe, in which a starting catalytic converter, a nitrogen oxide storage catalytic converter and an SCR catalytic converter are arranged one behind the other in the direction of flow, recurring nitrate regeneration phases being carried out in order to regenerate the nitrogen oxide storage catalytic converter, wherein the  $\text{NH}_3$  loading of the SCR catalytic converter is determined by the control unit, and the formation of nitrogen oxides by the internal-combustion engine is increased at least within the nitrate regeneration phases, the SCR catalytic converter in the exhaust pipe being arranged at least sufficiently far downstream of the nitrogen oxide storage catalytic converter for a temperature which is approximately  $50^\circ\text{C}$  to approximately  $150^\circ\text{C}$  lower than at the entry to the nitrogen oxide storage catalytic converter to be established at the entry to the SCR catalytic converter in most of the intended operating range of the internal-combustion engine.

2. A method according to Claim 1, wherein an upper threshold S1 is preset for the  $\text{NH}_3$  loading of the SCR catalytic converter, and at least within the nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter the formation of nitrogen oxides by the internal-combustion engine is increased if the  $\text{NH}_3$  loading of the SCR catalytic converter has fallen below the threshold S1.

3. A method according to Claim 2, wherein a lower threshold S2 is preset for the  $\text{NH}_3$  loading of the SCR catalytic converter, and the formation of nitrogen oxides by the internal-combustion engine is only increased within the nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter if the  $\text{NH}_3$  loading of the SCR catalytic converter has fallen below the threshold S1 but not below the threshold S2.

4. A method according to Claim 3, wherein within the nitrate regeneration phases for regeneration of the nitrogen oxide storage catalytic converter and immediately following the nitrate regeneration phases, the formation of nitrogen oxides by the

internal-combustion engine is increased if the  $\text{NH}_3$  loading of the SCR catalytic converter has fallen below the threshold S2.

5. A method according to Claim 3, wherein the formation of nitrogen oxides by the internal-combustion engine is increased if the  $\text{NH}_3$  loading of the SCR catalytic converter has fallen below the threshold S2.

6. A method according to Claim 1, wherein the formation of nitrogen oxides by the internal-combustion engine is increased at least from time to time while the internal-combustion engine is warming up.

7. A method according to Claim 3, wherein for the thresholds S1 and S2, a dependency on the respective temperature of the SCR catalytic converter and a dependency on the load demand imposed on the internal-combustion engine are preset.

8. A method according to any one of Claims 1 to 6, wherein the increase in the formation of nitrogen oxides by the internal-combustion engine is effected by changing the ignition angle and/or the fuel injection parameters of the internal-combustion engine.

9. A method according to any one of Claims 1 to 5, wherein an output signal from an  $\text{NO}_x/\text{NH}_3$  sensor arranged in the exhaust pipe, between nitrogen oxide storage catalytic converter and SCR catalytic converter, is used to determine the  $\text{NH}_3$  loading of the SCR catalytic converter.

10. A method for lowering the nitrogen oxide content in the exhaust gas from an internal-combustion engine operable selectively under lean and rich conditions, substantially as described herein, with reference to and as illustrated in, the accompanying drawings.



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Application No: GB 0206469.9  
 Claims searched: 1-10

Examiner: Dr Albert Mthupha  
 Date of search: 29 August 2002

# Patents Act 1977

## Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.T): B1W (WAX, WD, WX)

Int CI (Ed.7): B01D; B01J; F01N

Other: ONLINE; EPODOC; JAPIO; WPI

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	GB 2267365 A MERCEDES-BENZ, see Claims 1-4.	1 at least.
Y	EP 0802315 A2 TOYOTA, see column 29 line 41-column 30 line 5.	1 at least.
Y	WO 00/21647 A1 JOHNSON MATTHEY, see page 2 lines 29-31, page 3 line 17-page 4 line 2, page 7 line 22-page 8 line 17, Examples 1 & 3.	1 at least.

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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